Quarterly Review for Transmutation Science (1.25)
January 1, 2002- June 31, 2002

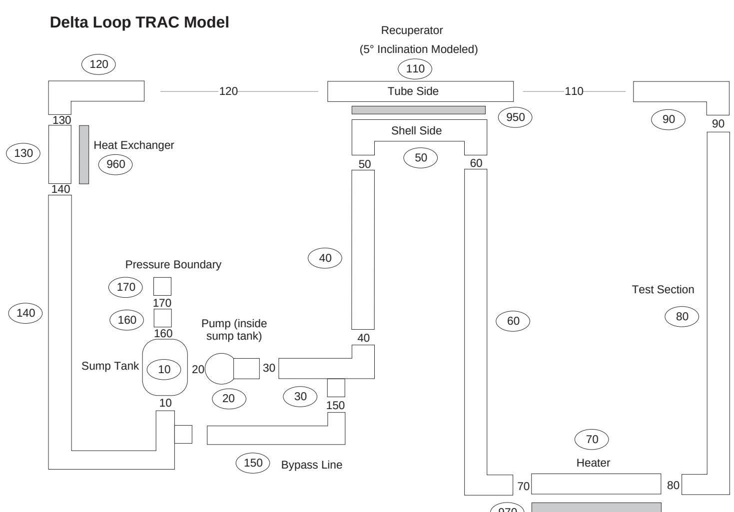
Highlights- Meetings and Papers

- Organized The Third International Workshop on the Utilization and Reliability of High Power Proton Accelerators, Santa Fe, NM May 12-16, 2002
- Co-organizer For The Fifth International Workshop on Spallation Materials Technology, Charleston, NC May 19-24, 2002
- Over 25 presentations and 35 publications starting with the ANS AccApp topical meeting in November, 2001.

Highlights-International Collaborations

- MEGAPIE collaboration continuing well: the design phase nearly completed, fabrication to start
- CEA collaboration: the majority of deliverables in the work packages delivered ahead of schedule
- ISTC#559 LBE test target TC-1 delivered to UNLV
- Other informal collaborations:
  - Julich, Germany for Ta handbook chapter
  - Karlsruhe, Germany for LBE technology
  - JAERI/KEK, Japan for spallation materials technology
  - Belgian Nuclear Research Center, spallation materials information for MYRRHA project

Highlights for LBE Technology Development Jan.-June, FY02



- Oxygen Sensors installed in DELTA
- Start of hydrogen/steam mixture system to calibrate oxygen sensors
- Oxygen control methodology and calibration strategy report issued
- Corrosion modeling improved the model prediction and mapped the average corrosion rate of DELTA Loop (2 papers under preparation)
- A TRAC model for DELTA established to benchmark the modification incorporating LBE features (validated TRAC will be used to support MEGAPIE safety studies)

Highlights Blue Room Expts.

- **H/He Production Tests-**
  - A new measuring station was established at 30-degrees-right for higher neutron flux at the higher energies
  - Preliminary measurement made on Fe foil
  - Preparing for beam measurements starting July 19th
- **Corrosion and Oxide Layer Tests-**
  - Scheduled for September 23, 2002
- **LBE Target Neutron Yield and Spectrum Tests-**
  - Recently acquired two summer students, Danny Lowe (UNLV) and Jim Platte (U. of Mich.) who are helping prepare for the experiment.
  - Fabricated large LBE target (40 cm diameter) and prepared activation foils.
  - Finishing preparations for beam measurements to start July 8th.

Progress on Materials Handbook

- A draft of Materials Handbook Chapter 19 (T91 [9Cr-1MoV] Ferritic/Martensitic Steel) was completed in April and a first review of this draft was accomplished at LANL. The chapter should be ready for final formatting early in the next Quarter.
- The first draft of Materials Handbook Chapter 22 (Pb-Bi Eutectic) was received in May from H. Glasbrenner at PSI. It should be ready for a final review and formatting in the next Quarter.
- Revisions were made to Section 7.5.2.4 (Effects of Irradiation on Yield Strength) of Chapter 7 (Tungsten) to incorporate data from compression tests on small tungsten cylinders irradiated in LANSCE. Reviews are in progress.
- Corrosion sections in Chapters 2 on Alloy 718 (Section 2.4.10), 3 on 316LSS (Section 3.4.10), 4 on 6061-T6 aluminum (Section 4.4.10), and 7 on tungsten (7.4.10) were revised in June to incorporate results from corrosion tests conducted during 800MeV proton irradiation at LANSCE. Reviews are in progress.

Future FY'02 Materials Analyses

- Finish Installation of high temperature furnace at hot cell to test up to 700C in argon.
- Test specimens irradiated at up to 250C to a total dose of 9 dpa with SINQ proton accelerator at 400-600C
  - Mod 9Cr-1Mo
  - F82H
- Test tungsten in compression at 600C after irradiation.
- Test shear punch strength of tantulum at 400-600C after irradiation
- Test tensile strength of SINQ irradiated specimens at 400-600C
  - EP-823
  - HT-9

Recent Progress on Materials Analysis at LANL Hot Cells

- Ordered and received high temperature furnace for testing up to 700C in argon.
- Received Zircalloy clad rods of 316L, F82H and Mod 9Cr-1Mo from STIP-I irradiation at PSI
  - Received total dose of ~9 dpa
  - Irradiated at a maximum temperature of 250C

Overview of FY02 Q3 Research Activities

- **Tensile Testing**
  - **Elevated temperature tensile properties analysis**
    - **» Analysis of data from unirradiated and irradiated specimens**

- **Transmission Electron Microscopy**
  - **TEM of Mod 9Cr-1Mo after 1.4 dpa at 35-70°C and thermally aged for about 2 hours at 500°C.**

- **Summary and Conclusions**

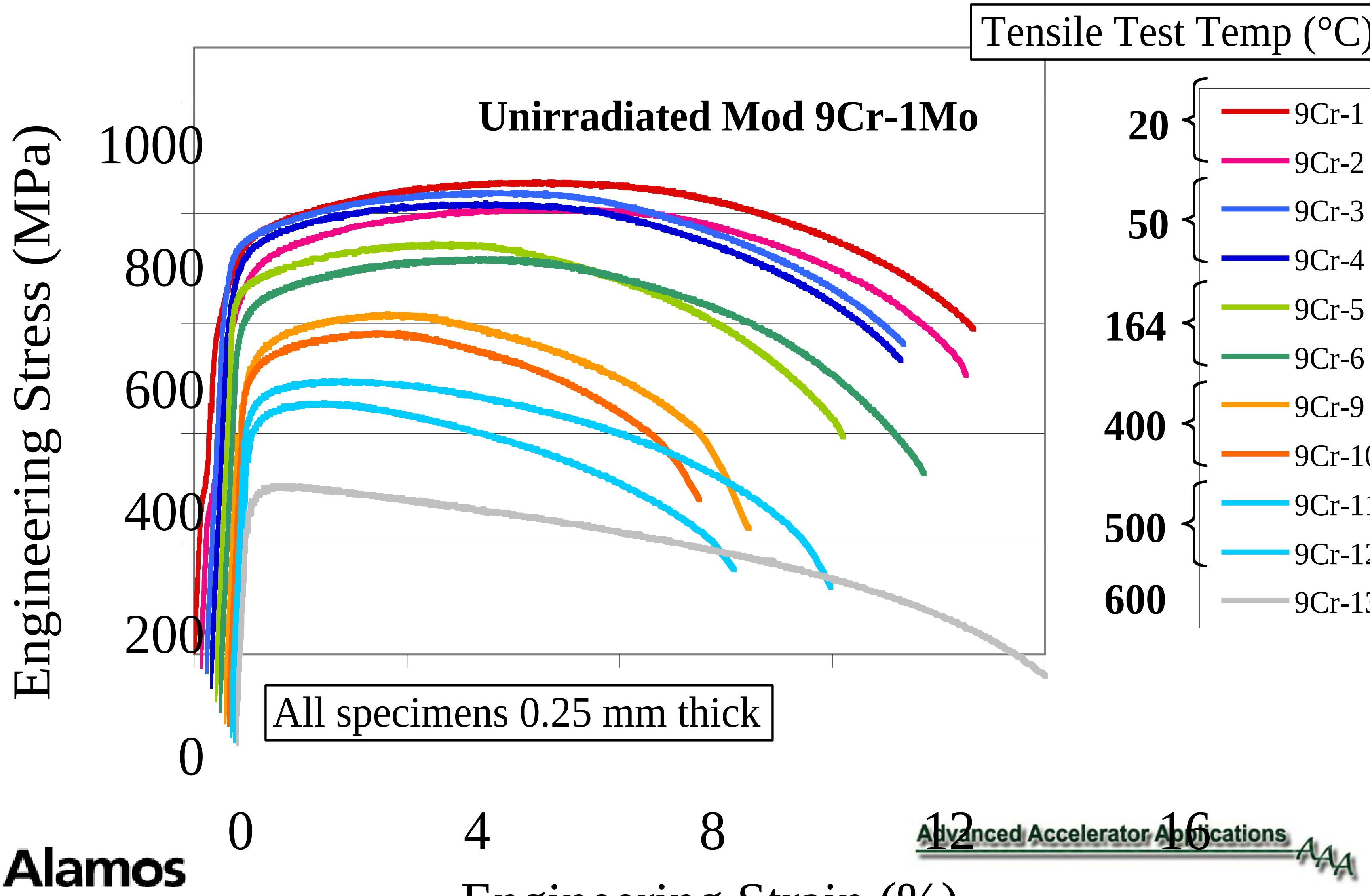
Recent Progress

- Recent research progress includes an analysis of the elevated temperature tensile properties of Modified 9Cr-1Mo after irradiation to doses between 1 and 3 dpa and to 9 dpa.
  - Tensile test temperature range was from room temperature to 600°C.
  - Specimens tested at 400-600°C were held at the test temperature for about 2 hours prior to the onset of the test.
  - Unirradiated and irradiated specimens

- Transmission electron microscopy was performed on Modified 9Cr-1Mo that had been irradiated to 1.4 dpa and then was thermal aged at 500°C for about 2 hours.
  - It was postulated that thermal aging at 500°C may induce bubble formation and other changes in the microstructure such as a reduction in black spot damage.

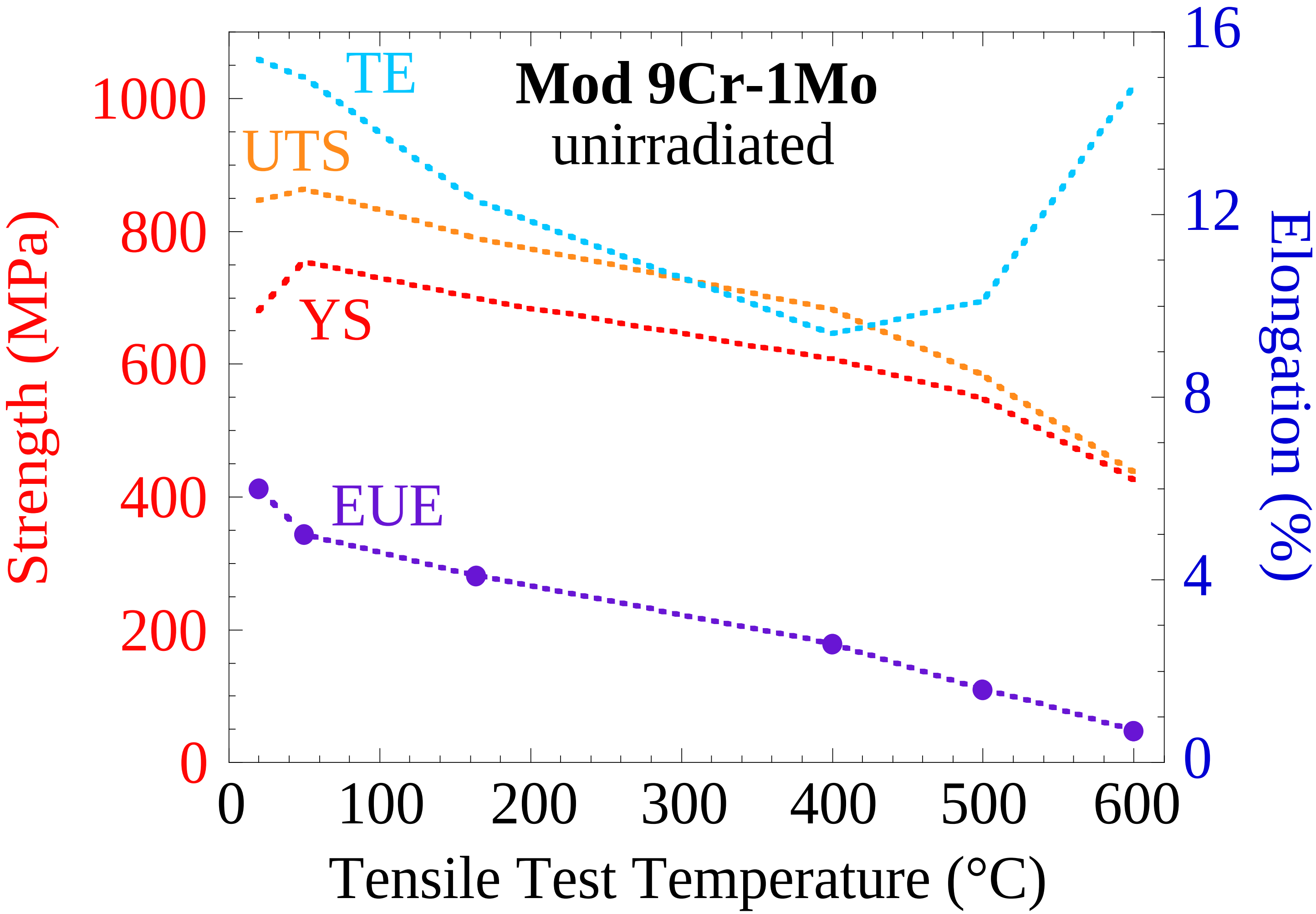
Results - Unirradiated Test Traces

- **Excellent reproducibility**



Results - Unirradiated Tensile Properties

- **Temperature dependent tensile properties are typical for unirradiated ferritic-martensitic steels.**



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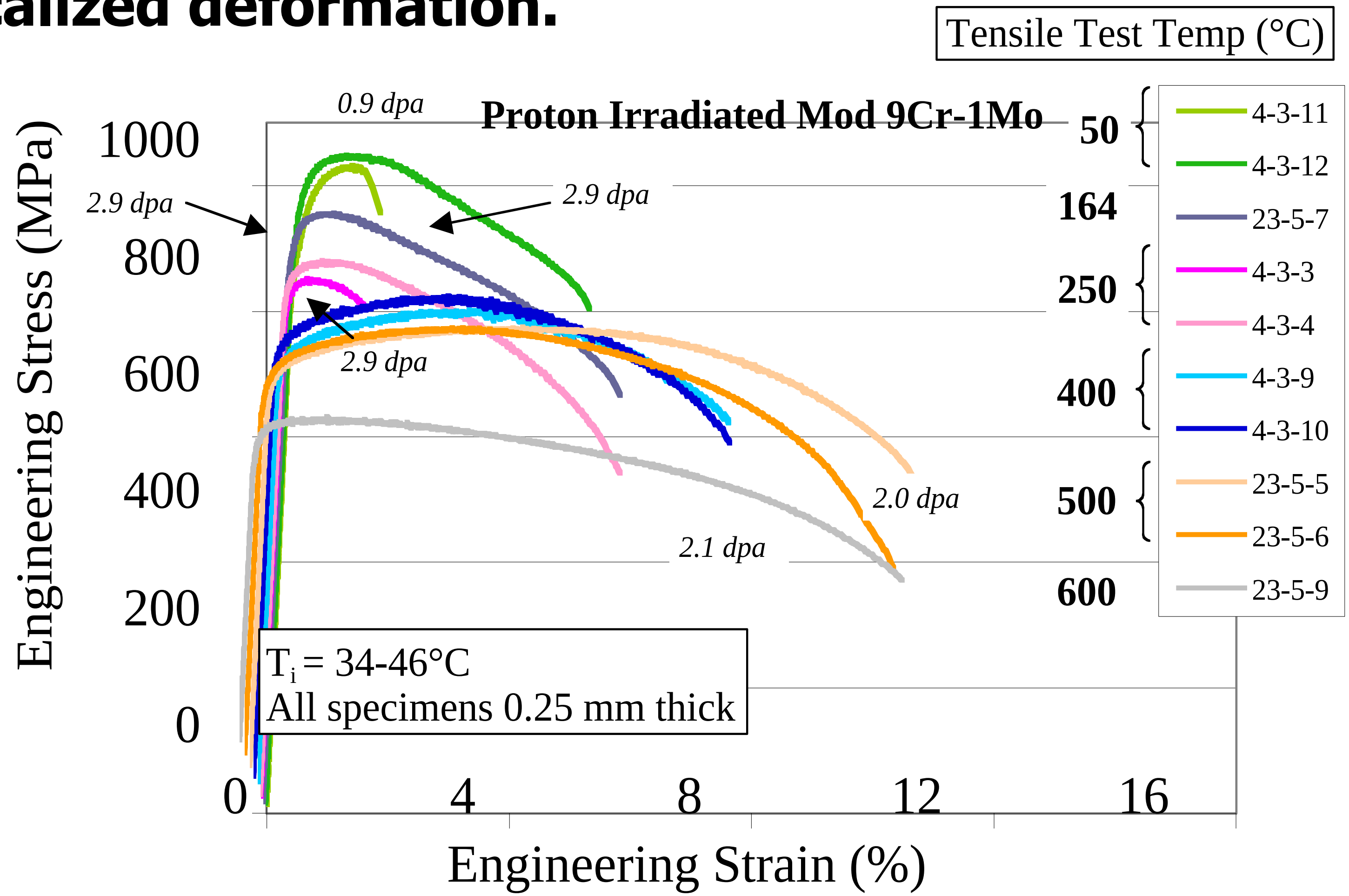
Advanced Accelerator Applications

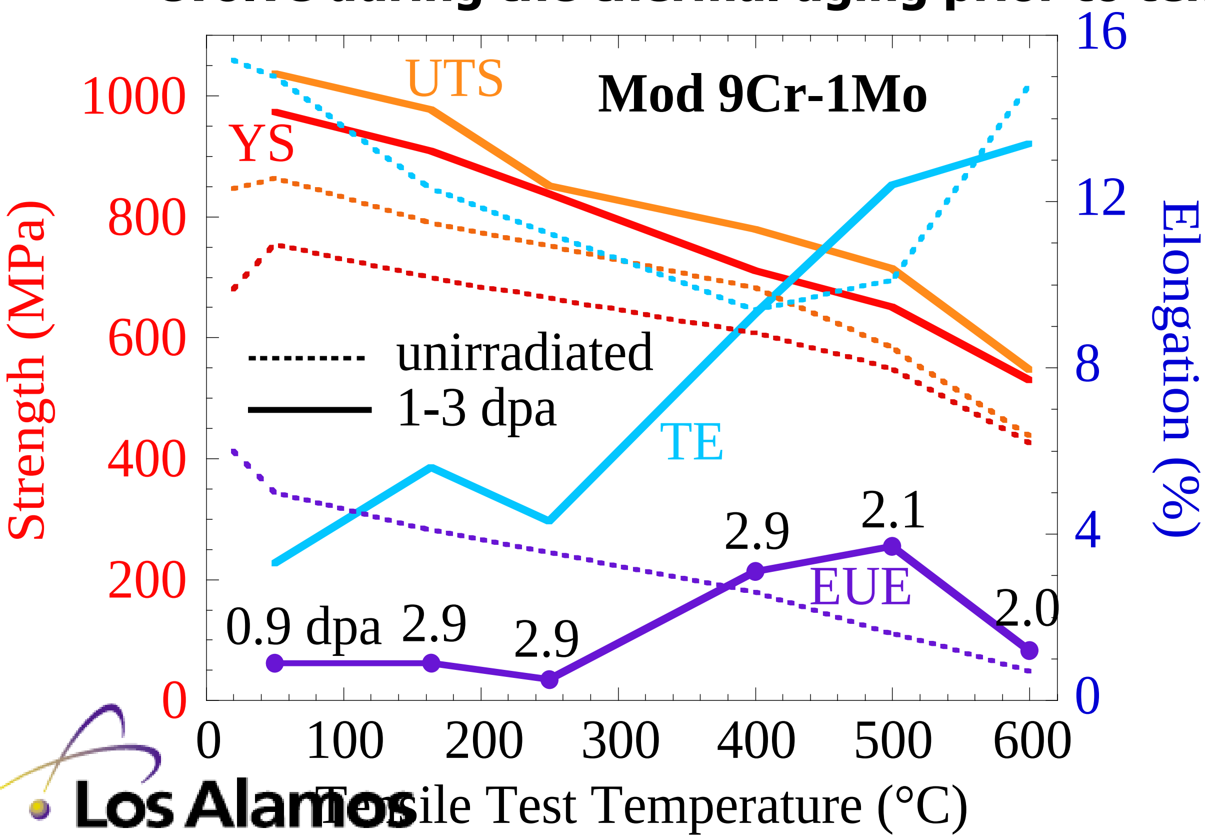
Results - Test Traces after 1-3 dpa

- **Very good reproducibility where 2 tests were performed.**
- **At lower test temperatures, loss of UE is indicative of localized deformation.**



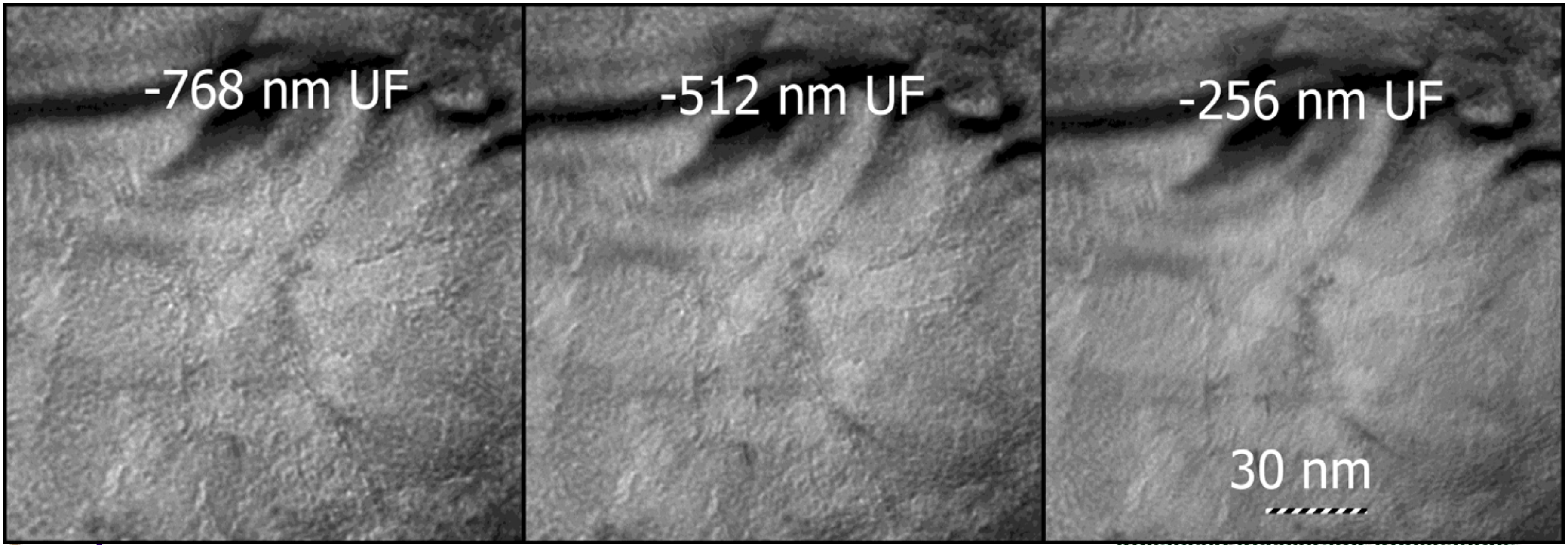
Results - Tensile Properties after 1-3 dpa

- **YS and UTS of irradiated material follow that of unirradiated material.**
- **UE and TE are less than the unirradiated values between 50°C and 250°C, but equal to or better than unirradiated at 400°C and 600°C.**
  - **Improved elongation is due to the irradiation-induced microstructural changes. At 400°C to 600°C, did the irradiation-induced microstructure evolve during the thermal aging prior to tensile testing?**



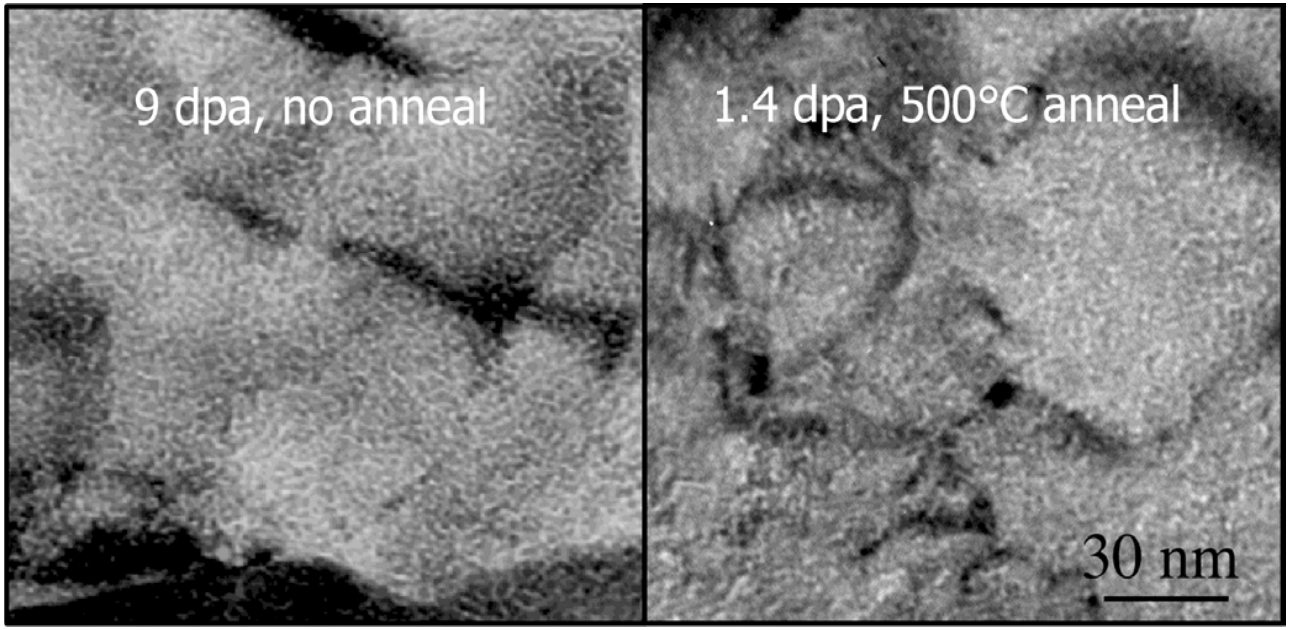
TEM examination of Mod 9Cr-1Mo aged at 500°C

- Irradiation conditions: 1.4 dpa at 35-67°C
- Possible changes to microstructure due to thermal aging include:
  - Bubble formation
  - Coarsening or a reduction in black spot damage
- Bubbles were not observed in through focus examinations.
  - Texture is an artifact caused by out-of-focus condition.
- Black spot damage assessment has not been performed yet.



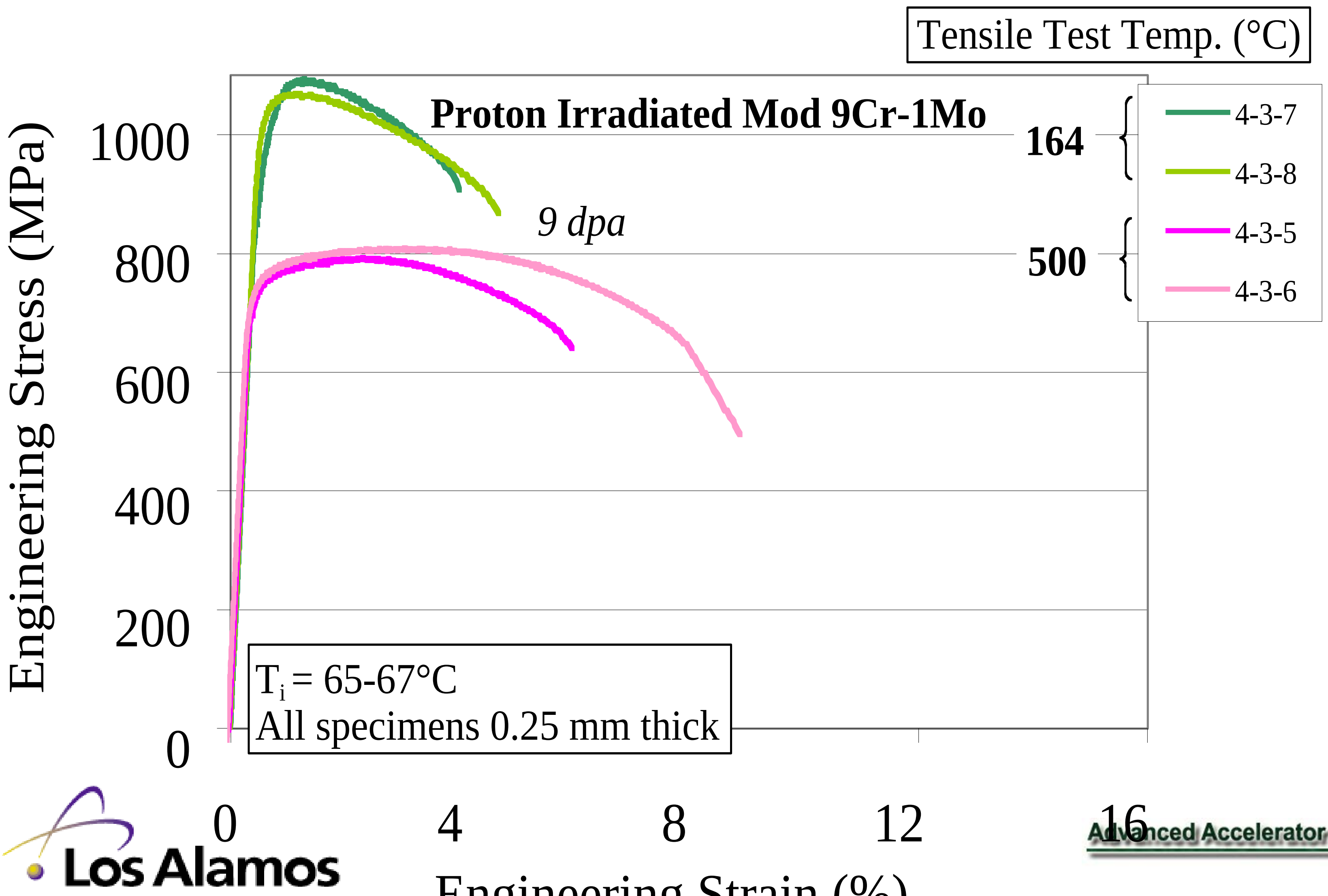
TEM examination of Mod 9Cr-1Mo aged at 500°C

- **Comparison to 9 dpa specimen not thermally aged.**
- **Images are comparable in appearance.**
  - **Texture is slightly different in appearance, but this is due to differing focus conditions.**



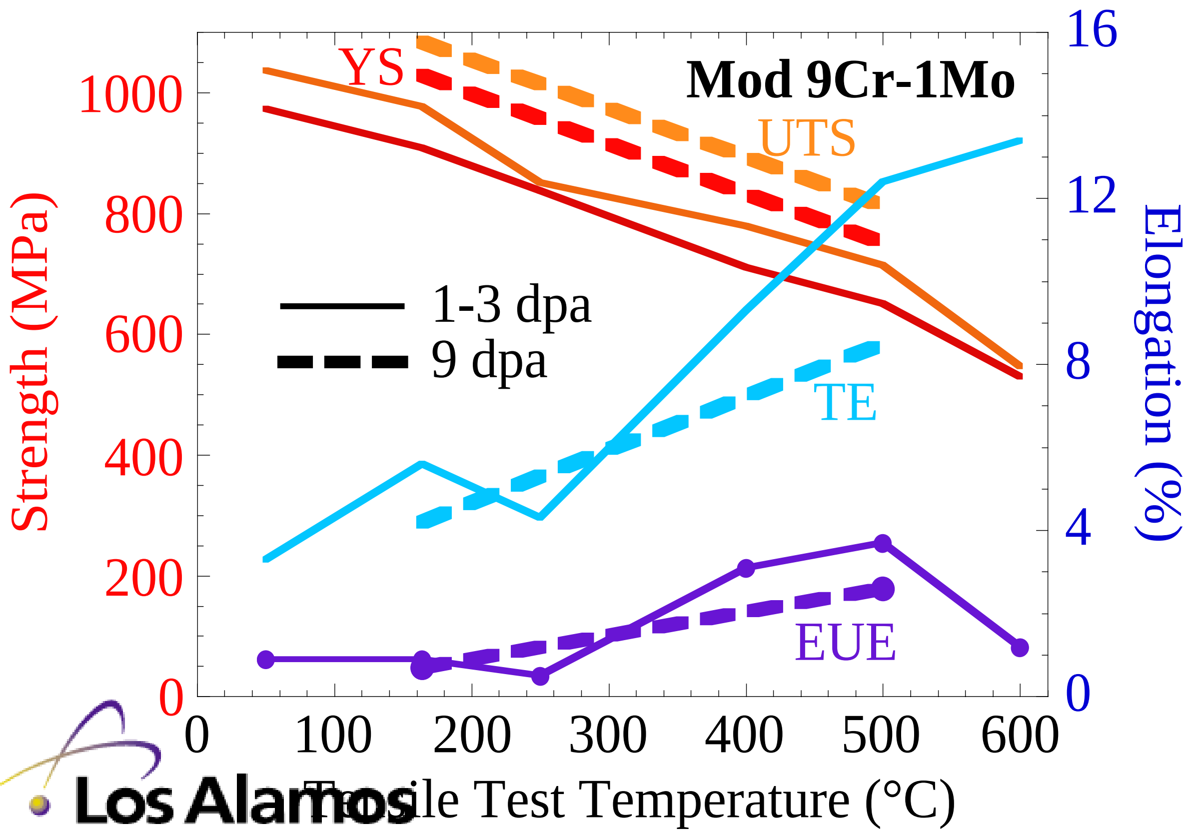
Results - Tensile Traces after 9 dpa

- **Behavior is similar to that observed after 1 to 3 dpa.**



Results - Tensile Properties after 9 dpa

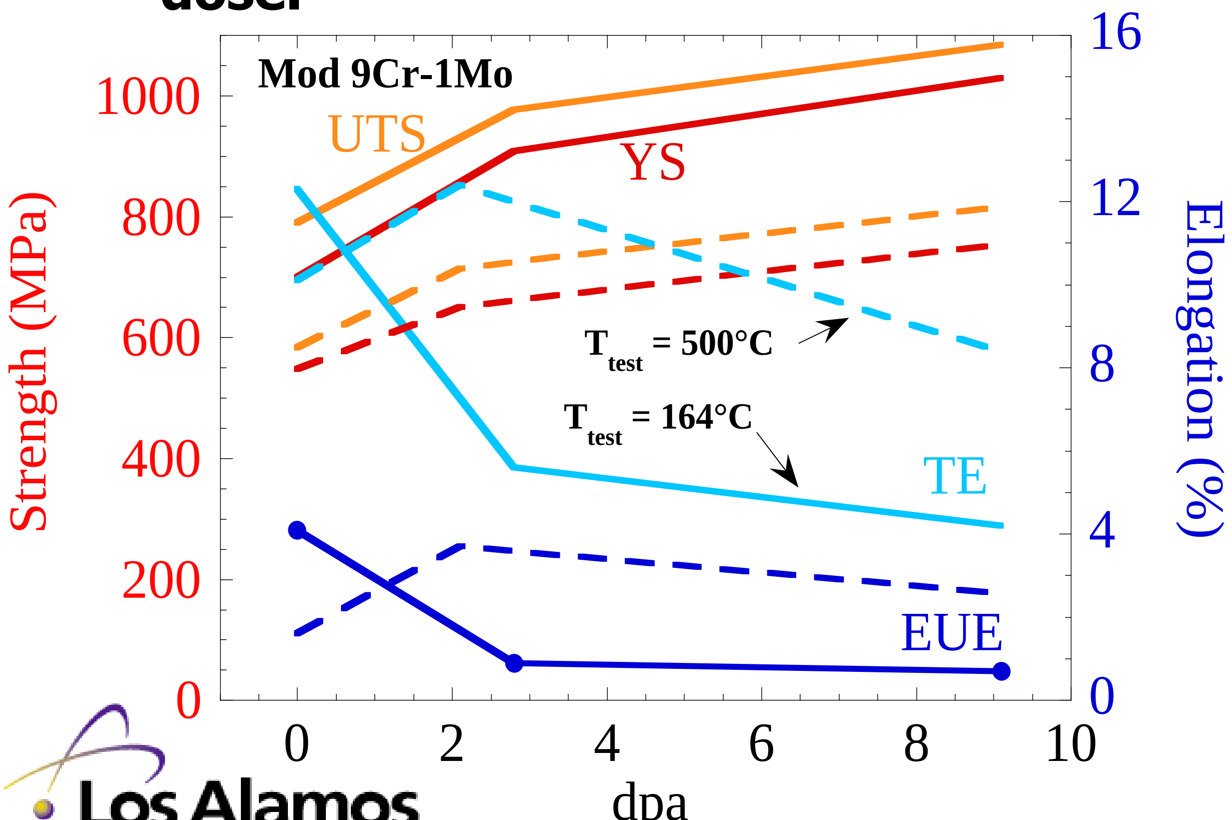
- **Temperature dependent trends at 9 dpa are similar to trends at 1-3 dpa but with small changes in magnitude.**
  - **YS and UTS are higher at 9 dpa.**
  - **UE and TE are lower at 9 dpa.**



- **At 500°C, UE after 9 dpa is below that after 2.1 dpa.**
  - **At 500°C, irradiation-induced improvement in UE after irradiation peaks at some dose less than 9 dpa.**

Results - Tensile Properties vs. Dose

- YS and UTS both increase with increasing dose at 164°C and 500°C.
- UE and TE
  - At 164°C, UE and TE degrade with dose.
  - At 500°C, UE and TE initially improve and then degrade with dose.

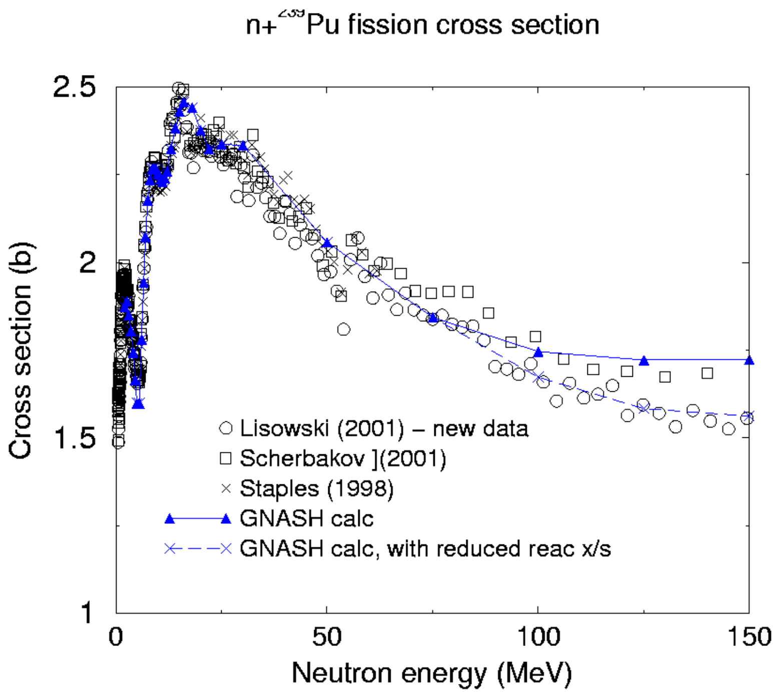


Summary and Conclusions

- Tensile tests were performed at 50°C to 600°C on Modified 9Cr-1Mo irradiated at 35°C to 67°C.
- YS and UTS after irradiation follow the same temperature dependence as the unirradiated material, but values are higher in the irradiated material.
- UE behavior of irradiated materials
  - Between 50°C and 250°C, UE is 1% or less, falling well below the unirradiated values and suggesting localized deformation.
  - At 400°C to 600°C, UE is equal to or better than the unirradiated values for doses up to 1-3 dpa. Improvement is dose dependent with a *peak* at some dose less than 9 dpa. This improvement must be due to microstructure formed by irradiation.
- Annealing at 500°C/2 hr of specimens irradiated to 1.4 dpa does not result in the formation of bubble.
  - Black spot damage evolution has not yet been investigated.

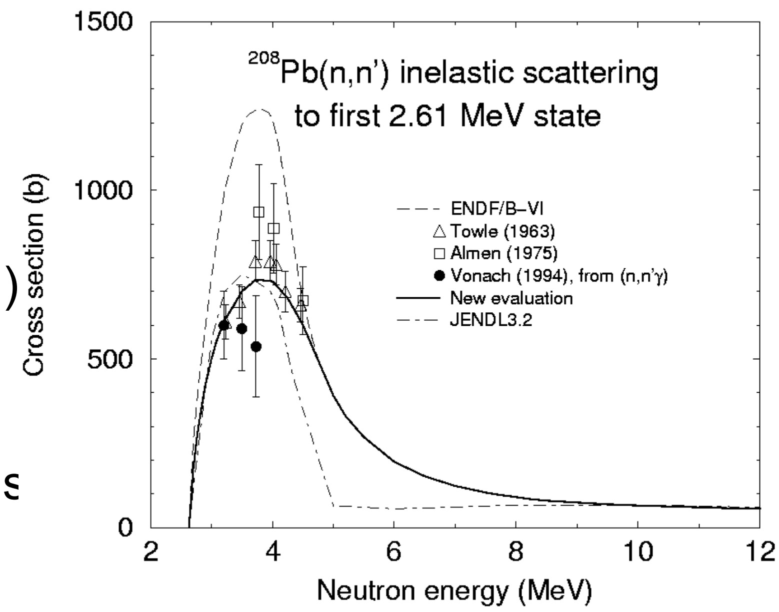
New ENDF high-energy (LA150) cross sections for actinides (^{239}Pu, ^{238}U) (Talou, Chadwick, Young)

- Important in MCNPX for more accurate simulations of criticality, neutron production, damage, heating
- Extends our APT "LA150" library for MCNPX. Widely used in the US, Japan, & Europe ADS programs. (Our Nucl Sci. Eng. 1999 paper on these cross sections cited > 40 times in refereed journals)
- Nuclear reaction theory in GNASH code is used to model (n,xn) and fission. LANSCE/WNR high-energy fission and total cross section data are important for these evaluations.



New ^{208}Pb inelastic scattering ENDF cross sections for accurate k_{eff} ATW criticality (Chadwick, Young)

- Deficiencies in previous ENDF data, in the fast energy region, were noted by ANL (Finck et al.), and European & Russian ATW researchers, since the impact on ATW criticality for a Pb-Bi system is high
- We have produced a new ENDF evaluation, that better represents the inelastic scattering
- Nuclear theory was used, together with experimental data (including data from LANSCE/WNR – Vonach)
- ATW criticality calculations by Embid (Int. Conf. On Partitioning & Transmutation, European Commis indicate a ~ 2.5% effect on k_{eff}.

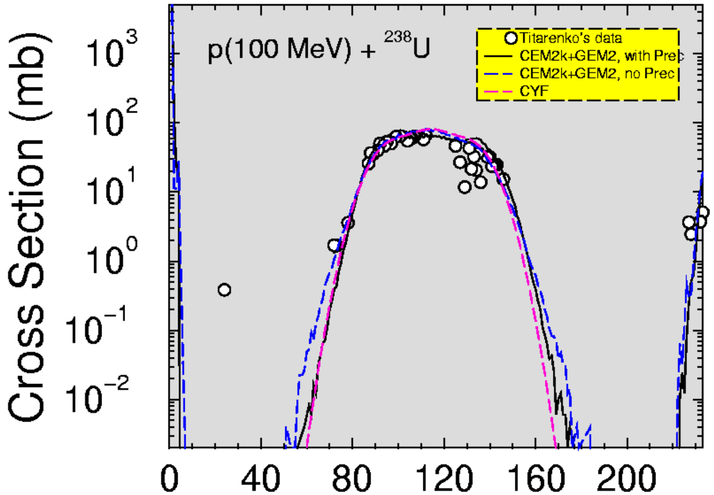


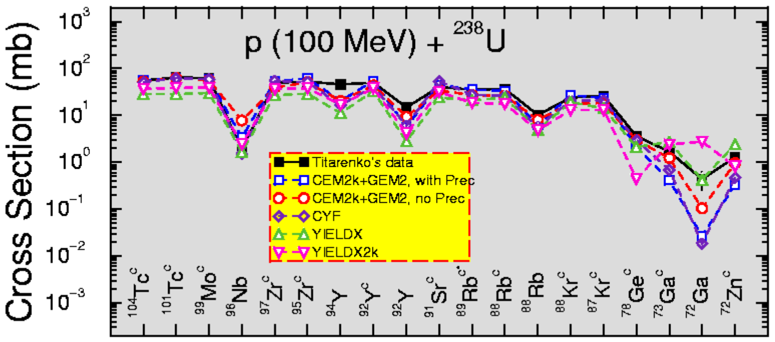
Prompt fission neutrons for LA150 actinide AAA cross section evaluations (Mashnik)

- CEM cascade code (T-16) is used to model & evaluate the number and spectra of prompt neutrons emitted from decaying fission fragments

- We have developed a new fission model within CEM

- We have undertaken extensive benchmarking of our code against available experimental data, as well as comparisons with other modern cascade code predictions *(excellent CEM results obtained)*

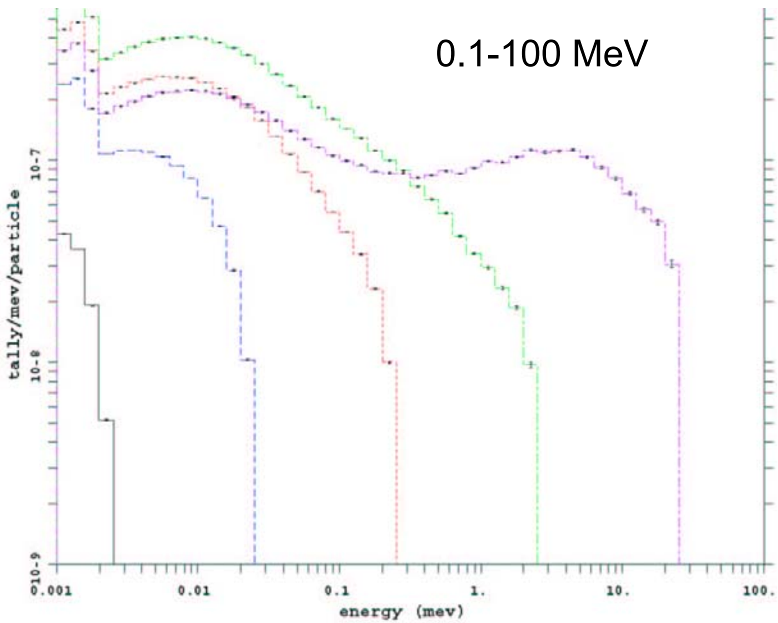




MCNPX Code Progress

- Issued revised Users's Guide for the RSICC release of MCNPX 2.3.0
- Released MCNPX version 2.4.j to the beta test team
  - Fully compatible with MCNP4C
- Included light ion recoil into the code so that light residual nuclei are treated as fully transportable particles, including a Fermi Gas treatment for protons. This improves the accuracy of energy deposition calculations in light materials.

Energy spectra of helium-3 residual nucleus recoil



- Produced the first fully parallel version of the code. This has been tested on a Linux cluster at LANL, including both the 'tabular' and 'physics' regions. It will shortly be released as version 2.4.k
- Received latest version of CEM2K from Oak Ridge for inclusion in the code.
- Set up ftp site for download of Saclay physics models (Cugnon INC and Schmidt Evaporation) for inclusion in the code.

MCNPX Code Progress, con't.

- Attended the ANS Radiation Protection and Shielding meeting in Santa Fe from April 14-27
  - 21 papers MCNPX-related were presented
- Taught 20 students in a 5-day MCNPX class in Santa Fe, April 19-24
- Visited PSI June 19-20 for an advanced MCNPX workshop with AAA collaborators on MEGAPIE
- Held 5-day MCNPX class in ITN, Portugal for 27 students, co-sponsored by NEA.
  - Class includes researchers from CEA Saclay, Cadarache, PSI
- MCNPX beta test team now includes 892 users from 194 institutions internationally.

Gas Production Cross-Section Measurements at LANSCE

Quarterly Review
July 10-11, 2002

Robert Haight and Matthew Devlin
LANSCE-3
Los Alamos Neutron Science Center

Outline

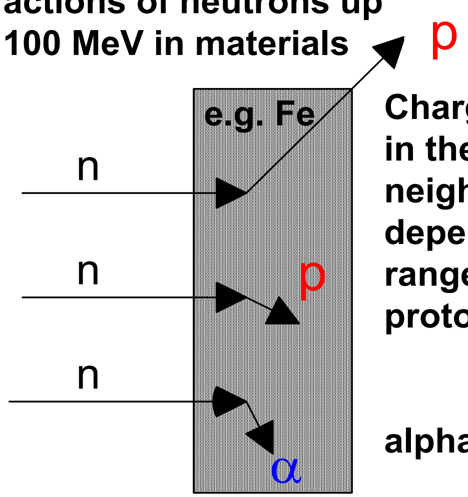
- Goals
- Methods
- Preliminary results
- Planned measurements
- Summary

Our goal is to measure hydrogen and helium production cross sections on structural materials for En < 100 MeV

- Need for such data
  - hydrogen and helium are produced by reactions of fast neutrons with structural materials and can cause adverse effects on the properties of these materials
  - production cross sections are necessary input to assess these effects
  - most of the neutrons in an accelerator driven system are below 100 MeV
  - very few experimental data exist for neutron energies above 50 MeV
  - new evaluations (e.g. Chadwick et al.) are based on physics models which need to be validated

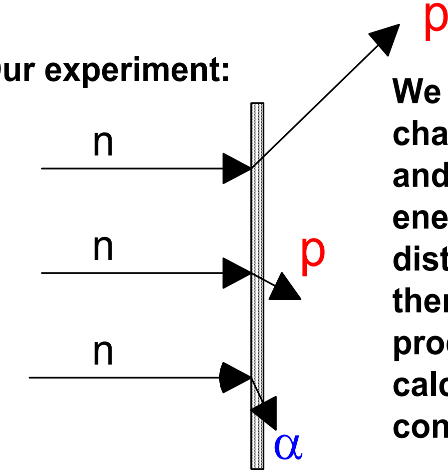
Hydrogen and helium are produced by neutron reactions in materials

Interactions of neutrons up to 100 MeV in materials



Charged particles stop in the material or neighboring materials, depending on the range:
protons -- mm to several cm-> hydrogen
alphas - mm -> helium

Our experiment:



thin foil - to let particles escape with little energy loss

We detect outgoing charged particles and measure their energy and angular distributions -- then H and He production can be calculated with confidence.

$$(n,xp) + (n,xd) + (n,xt) = (n, \text{Hydrogen})$$

$$(n,x^{3}He) + (n,x\alpha) = (n, \text{Helium})$$

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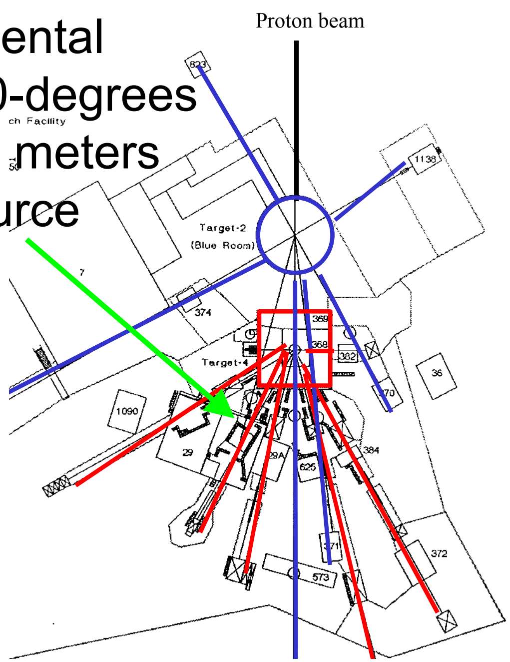
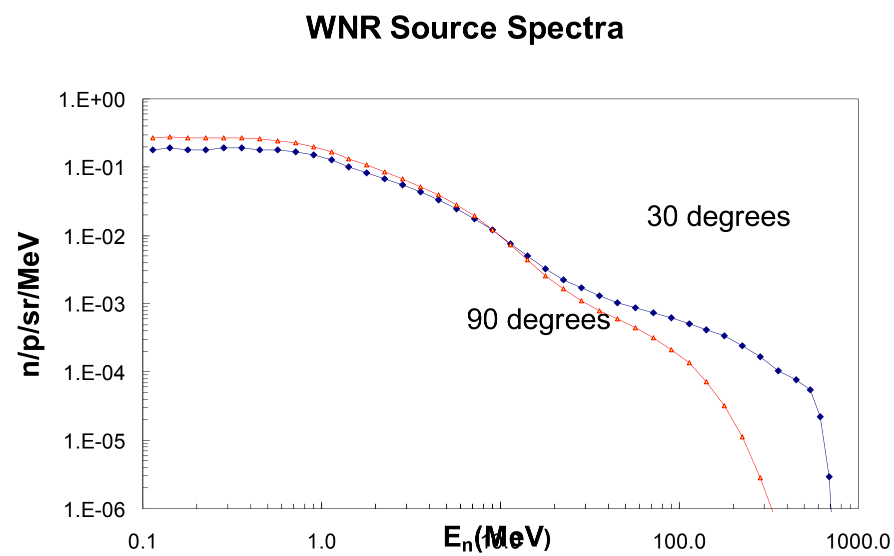
Advanced Accelerator Applications AAA

The WNR neutron source is ideal for these measurements

- The neutron spectrum extends from 0.1 MeV to several hundred MeV
- The intensity is the largest in the world
- Experimental areas have good infrastructure

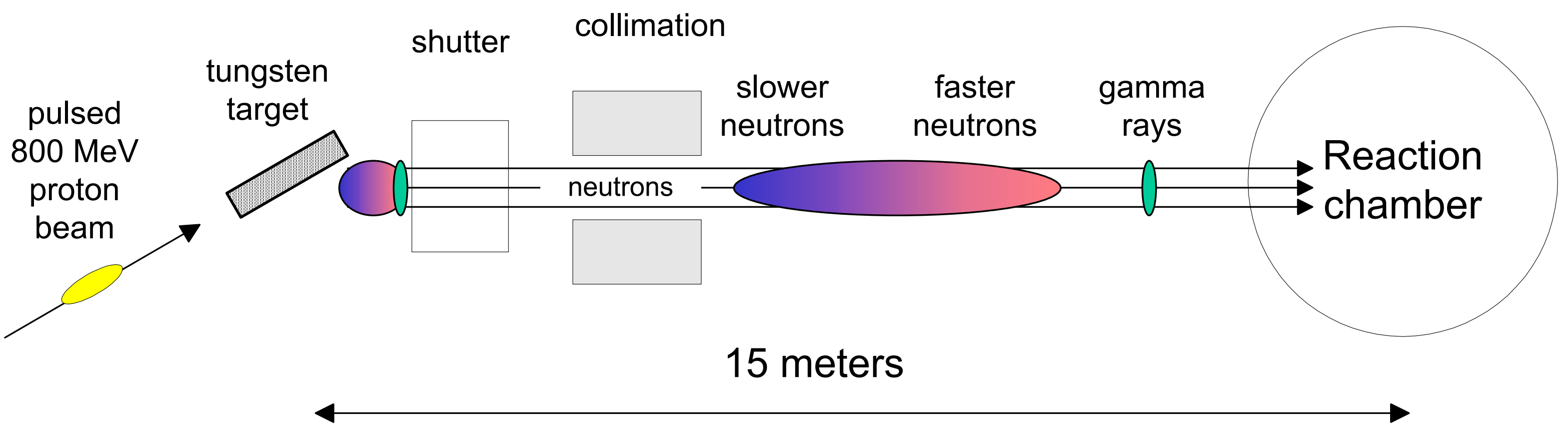
our experimental station at 30-degrees right and 15 meters from the source





We can study these reactions as a function of neutron energy with the time-of-flight technique

Time of flight over the flight path identifies the energy of the neutron that induces the reaction



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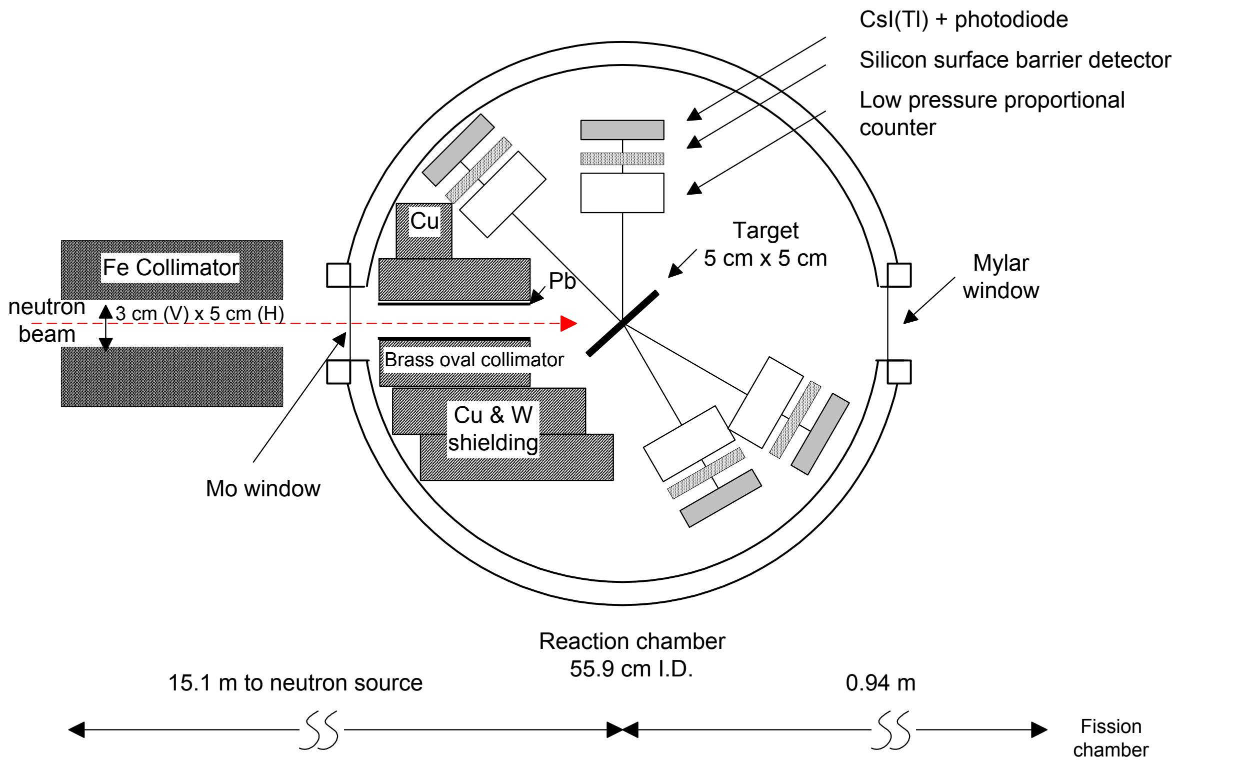
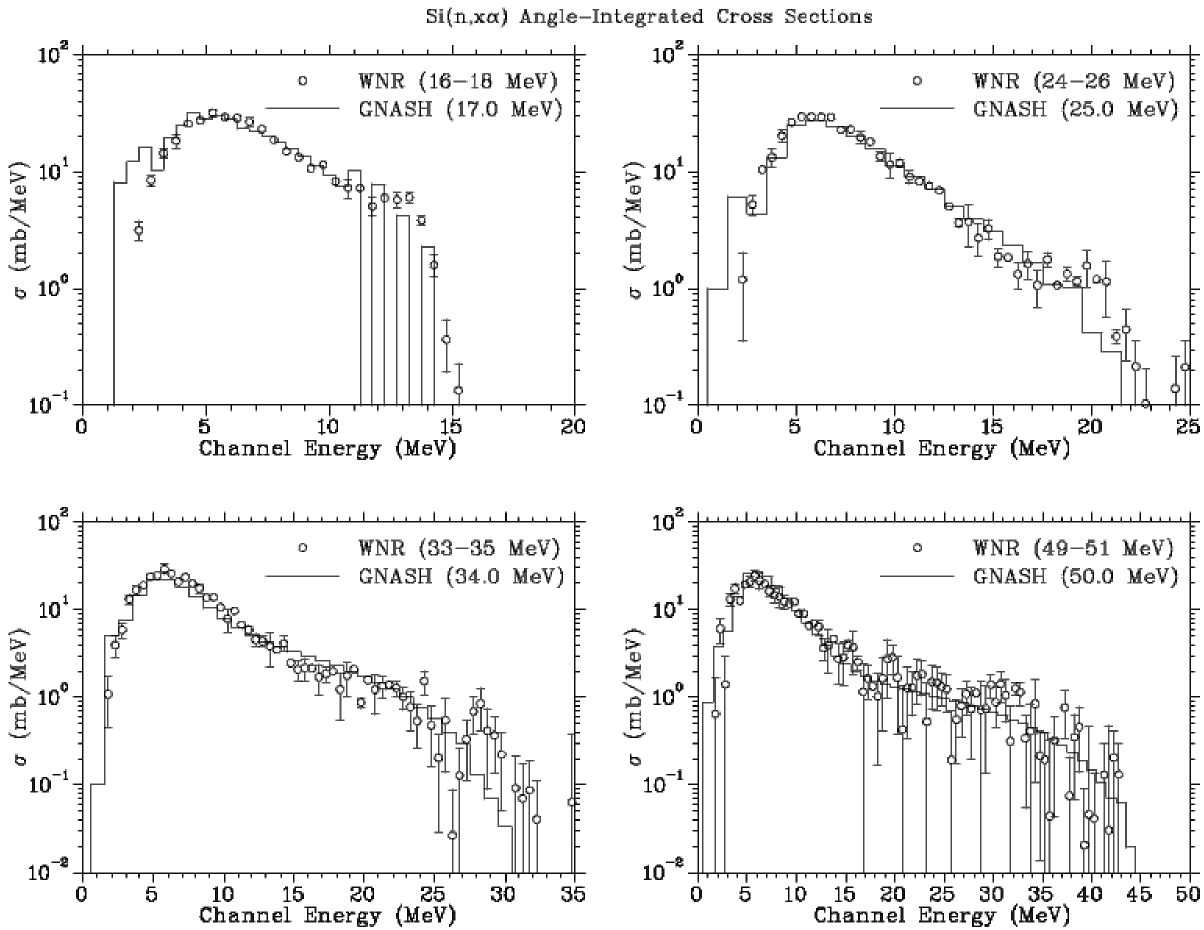
We identify light charged particles and measure their energy with appropriate detectors

- Three detectors in coincidence are used.
- Proportional counters and silicon detectors identify the particles.
- These detectors plus CsI(TI) scintillators measure the energies of the particles.



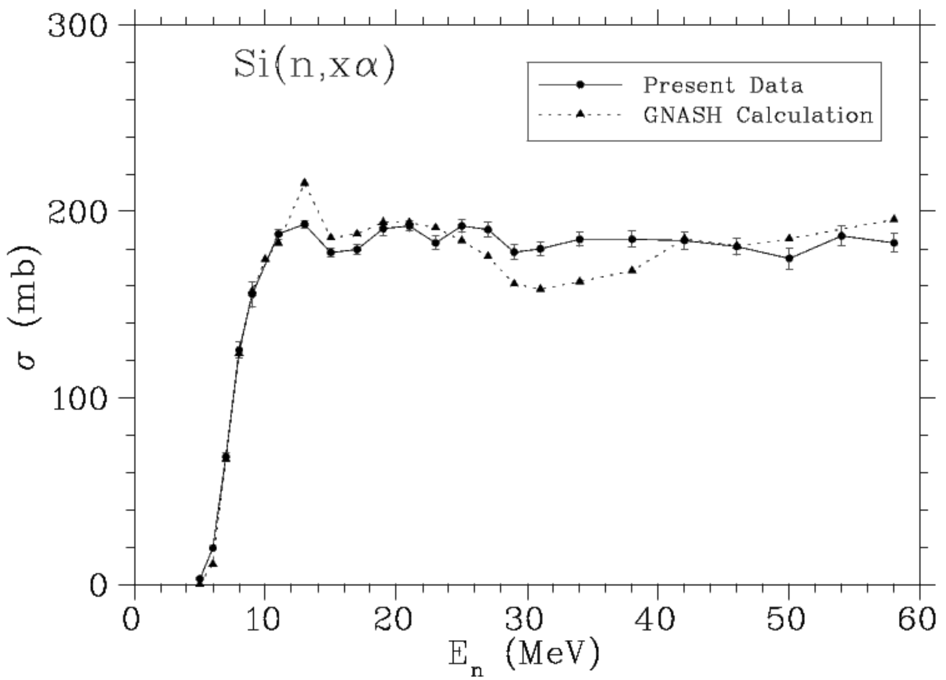
Our previous work has shown the type of data to be expected

- These are the energy spectra -- integrated over angle -- of alpha particles emitted in reactions of neutrons with silicon.
- Four regions of incident neutron energy are shown.
- Note the evaporation-like spectra with a high energy tail at the higher neutron energies.



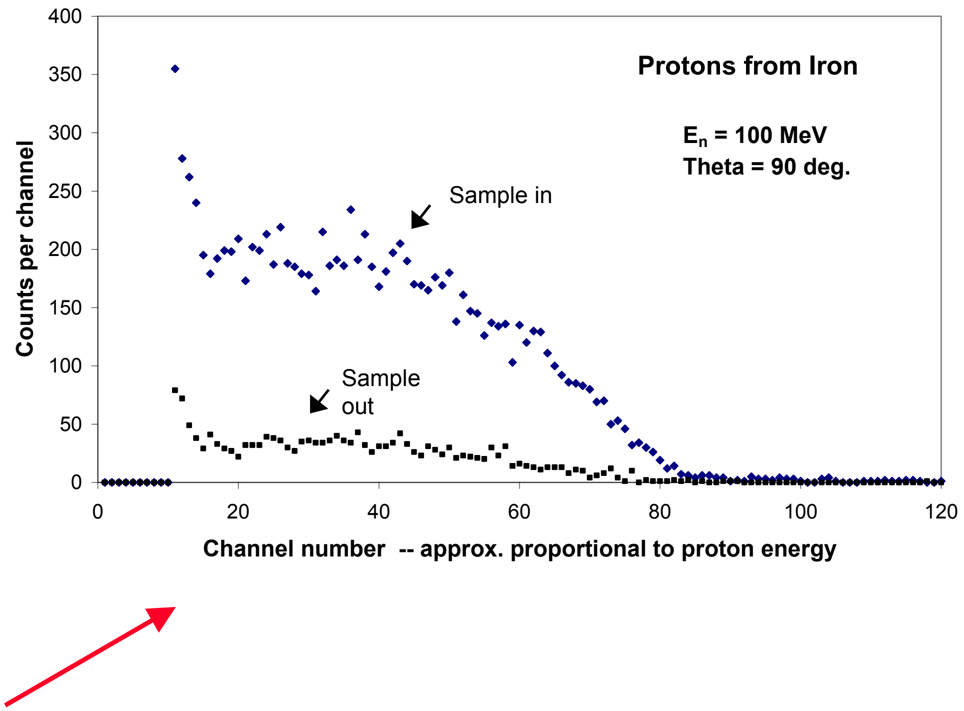
Integrating the energy spectra gives the production cross section

- Our previous studies extended to E_n = 60 MeV
- In this case of silicon, the nuclear model calculations (GNASH) were shown to be very good over most of the neutron energies studies



We have made preliminary measurements on iron

- A new measuring station was established at 30-degrees-right for higher neutron flux at the higher energies.
- Collimation and shielding were installed.
- The reaction chamber, detectors and electronics were relocated to this station.
- A preliminary measurement was made on an iron sample.
- Good signal-to-back ground was obtained.



Production runs will begin this summer

- Iron and another material (chromium or a stainless steel will be studied
- Hydrogen and helium production cross section data will be obtained up to En = 100 MeV
- Data on the energy spectra and angular distributions of emitted charged particles will be obtained to further test the nuclear reaction models
- In FY2003 we plan to study other materials as selected by the AAA program -- perhaps Mo and other stainless steels

Personnel -- all in LANSCE-3

- Robert Haight - Research Team Leader
- Matthew Devlin - Staff Physicist
- Dimitri Rochman - new postdoc - arrives 7/15/02
- Summer students
  - Graduate students (all first year)
    - » Sheila Lutz - Colorado School of Mines - Physics
    - » Matthew Hilt - Colorado School of Mines - Elec. Eng.
    - » Ana Maria Alpizar Pizenti - Colorado School of Mines - Physics
  - Undergraduate student
    - » Jacquelyne Gallegos - Univ. New Mexico sophomore
- Mechanical, electrical and computer technicians

Summary

- Hydrogen and helium production cross sections can be measured by detecting the light charged particles emitted in neutron-induced reactions (n,xp), (n,xd), (n,xt) (n,x^{3}He) and (n,xα).
- A new experiment station has been established.
- The performance of this station has been demonstrated to be appropriate for making these measurements.
- Production measurements begin this summer (first beam on July 19).